Structurally Failed Dam: A Case Study of Cham Dam, North-Eastern Nigeria

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Abstract
A geophysical investigation involving Shlumberger vertical electrical sounding (VES) profiling was conducted on a failed dam in Cham area, Upper Benue Trough, North eastern Nigeria. The raw VES data were used to prepare apparent resistivity curve, pseudosection and the geoelectric section along considered six VES points. The study indicates the subsurface as remarkably in-homogeneous in geologic composition. The geologic layers are defined by variable combination of siltstone, shally-clay, claystone, shale and clay which constitute the subsurface. The investigation indicated displacement at depth which correlates well with the failed segment of the dam. It is concluded from the study that the dam under investigation probably failed on account of displacement along suspected weak zones.
Keywords: Geophysical, Shlumberger VES, Dam, Displacement

Introduction
An adequate assessment of geologic and geotechnical conditions of the proposed site is imperative for a safe dam design and construction. The geologic and geotechnical problems range from foundation defects caused by inadequate investigation to internal erosion through the embankment. Each dam site may have its own unique set of geologic and geotechnical challenges since the design requirements are different for dams of different size, purpose and hazard potential classification (Ferguson,1992 and Coduto,1999.). Standard engineering practice requires investigation of the soil and the subsurface at sites chosen for engineering construction(s) (Olorunfemi *et al* 2000, 2005; Oladapo-Adeoye and Oladapo Ilesanmi 2011. The Geophysical and Geotechnical Investigation of Cham Failed Dam Project (Tabwassah and Obiefuna, 2012) prompted the study and examination the subsurface structural geologic condition of the failed dam in September 1998 after commissioning in December 1992. This would help in adding voice to standard engineering practice.

Physiography and Geology
The area is generally rugged undulating and dissected by numerous streams and rivers. The area is predominantly hilly prominent among them are the Cham hills, Nyiwar hills (1900m above mean sea level). The low land areas are composed of black cotton soils (product of weathered shale). The drainage pattern is generally dendritic network of streams and rivers. Prominent among the streams are; the Lafiya, Yolde and Cham Streams all flowing in a Southerly direction. The cretaceous Benue Trough of Nigeria is an intracratonic, intercontinental basin that stretches for about 1000m in length oriented NE-SW and uncomformably resting on the Precambrian Basement (Carter *et al* 1963, Benkhelil and Robineau, 1983, Benkhelil, 1989). Stratigraphically the upper Benue Trough comprises of two sub basins namely the Gombe and Lau sub Basins or the Gongola and Yola arms (Figure 1) represented by thick sequence of cretaceous sediments. The Lau Sub Basin of the upper Benue is stratigraphically underlain by continental and marine Cretaceous Aptian–Early Santonian deposits. The Bima sandstone is the oldest sedimentary sequence in the entire Benue Trough and was deposited under continental condition and is intercalated with carbonaceous clays, shale's and mudstones. The CenomanianYolde Formation lies conformably on the Bima Sandstone which represents marine incursion into this part of Benue Trough, and was deposited in a transitional/coastal marine environment. The Yolde is overlain by Lower Turonian marine Dukkul Formation.The Dukkul represents marine Formation which overlies the Yolde directly. It is composed of limestone, marlstone, mudstone and shale. The Jessu overlies the Dukkul Formation which consists of shale, siltstone, mudstone and Sandstones. The Cenomanian sequences are (sekuliye, Numanha and Lamja sandstones and Tertiary Basalts. The geological map of the study area is represented in figure 2

Materials and Method
Geophysical survey was carried out on the site. Vertical Electrical resistivity soundings were undertaken using ABEM SAS 4000 Terrameter by means of the Schlumberger system of electrodes arrangement. The points have a maximum electrodes separation of AB/2 equals 160m. This type of electrode configuration has been used World Wide with satisfactory results. The method of electrical sounding furnishes detail information on the vertical succession of different conducting zones and their individual thickness and true resistivity. For this

reason, the method is particularly valuable for nearly horizontal stratified ground. Seven VES stations were conducted along a profile that runs E-W about 1200 metres along the failed structure. This orientation was chosen in conformity with the W-E direction of the failed segment. The length of the traverse VES stations were determined by the length of the embankment about 1200metres and station interval of 200metres was adopted. The contoured apparent resistivity pseudo section was produced from plots of VES points against electrode spacing. The pseudo section was generated using IP12WIN Computer interpretation software. The curves were interpreted qualitatively through visual inspection and quantitatively using 1XD RESIX and IP12WIN Computer interpretation software's simultaneously. Interpreted results were used to construct geo-electric section from the layered parameter.

Results and Discussion

The field curves show three, four and five to six layers case (Fig.3-8). The sounding curves are H, HK, KHK and HKH types. The geoelectrical section of the survey area, and the resistivity contoured map covering a total horizontal distance of 1200m are presented in Figures 9-12 respectively. The area is underlain by shalely- clay and top soil to an average depth of 35m, and a siltstone bed extend to an unknown depth around VES 1, this is approximately similar to those of VES 2 and 3, while VES 4, is an array of chronologic lateritic dark clay to friable shale which extend to about 35m, this is immediately underlain by probable silty shale to muddy shale to an unknown depth below. VES 5 is characterized by abrupt high resistivity which indicates that siltstone out crops from about 50m to about 1.5m to the surface, this point is characterized by abrupt fall in resistivity between the depths of 10-25m; this represents a probable displacement (fault). VES 6 is characterized by shallow beds of siltstone at 1.5m to 45m, this is however cross cut by a minor fault between depths 35-45m. The Resistivity Contour Map of the same area from which the profile of the study area was plotted (Figure10), clearly indicates displacement at depth along VES 3 to 6. It shows that the western part of the studied area with reference to the starting point is underlain by high resistivity rocks at shallow depth of 1-40m.

The shape of this resistivity curves is related to the subsurface geology of the entire surveyed area. This show that moderate resistivity rocks occurs between 0-200m horizontally. This represents low resistivity rocks between the ranges of clay to shalely rocks. The resistivity increases steadily between 400m and 1000m horizontally, with its highest peak at approximately 700m horizontal distance, showing the existence of hard rocks from approximately 7m depth. Between 400m and 1200m, is shallow depth of higher resistivity rocks, these ranges in vertical depth from 1.5m to approximately 40m down the subsurface. The major (Figure 11) displacements are observed at depth 48m in VES1, 45m at VES 2 and between VES 2 and 3 at 25m depth and VES 6 at depth 53m down the subsurface. The table1 is a summary of events on the geoelectrical section of Cham dam axis.

Conclusion

Geophysical investigation involving Shlumberger (VES) was carried out on the dam in Cham area. Six VES stations were occupied. The VES survey identified four sounding curves namely, H, HK, KHK and HKH. The interpretation results of these curves delineated major four geologic units: siltstone, shally-clay, claystone, shale and clay. Resistivity along embankment indicated displacements. It could be concluded from the study that the dam under investigation failed on account of displacement along suspected weak zones. This gives credence to proper investigation of sites chosen for engineering construction(s).

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Table 1.Geo-electrical section of Cham dam axis

VES	Horizontal Distance (1:200m)	1st layer Top soil	2nd layer Shale/ Shally clay (m)	Interbeding layers of Mudstone	3rd layer Siltstone 1 (m)	Interbeding layers of Siltstone 2 (m)	Displacement at depth	Horizontal position of displacement (m)
01	0	0 - 4	4 – 40	-	40 – 55		48	140
02	0-200	0 - 2	2 – 33	-	36 – 53	36 – 53	37	340
03	200-400	0 - 2	2 – 24	-	24 – 53		32	500
04	400-600	0 - 1	10 –21	-	21 – 43	-		
05	600-800	0 - 3	4 – 19	-	19 – 46	-	3	1120
06	800-1000	0 - 4	4 – 10	-	10 – 29	-	47	1200

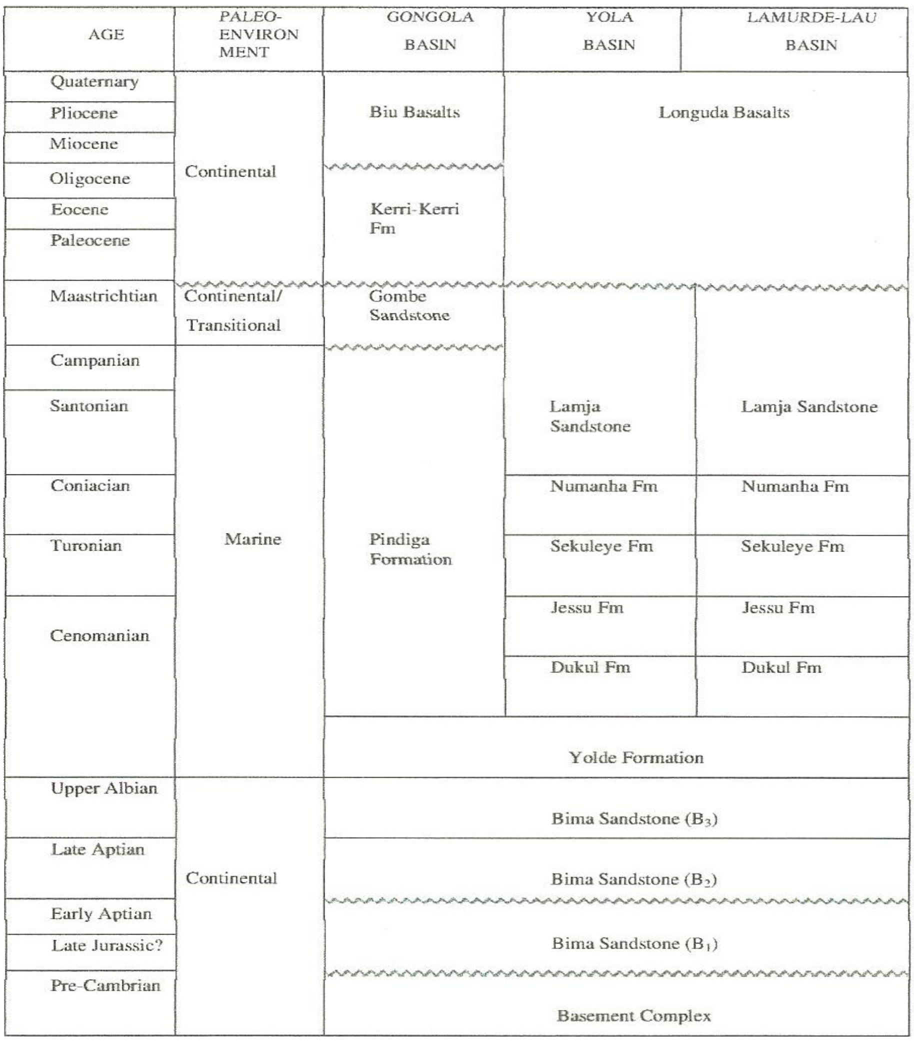

Figure 1. Stratigraphic succession of the Upper Benue Trough (after Samaila *et al* 2008)

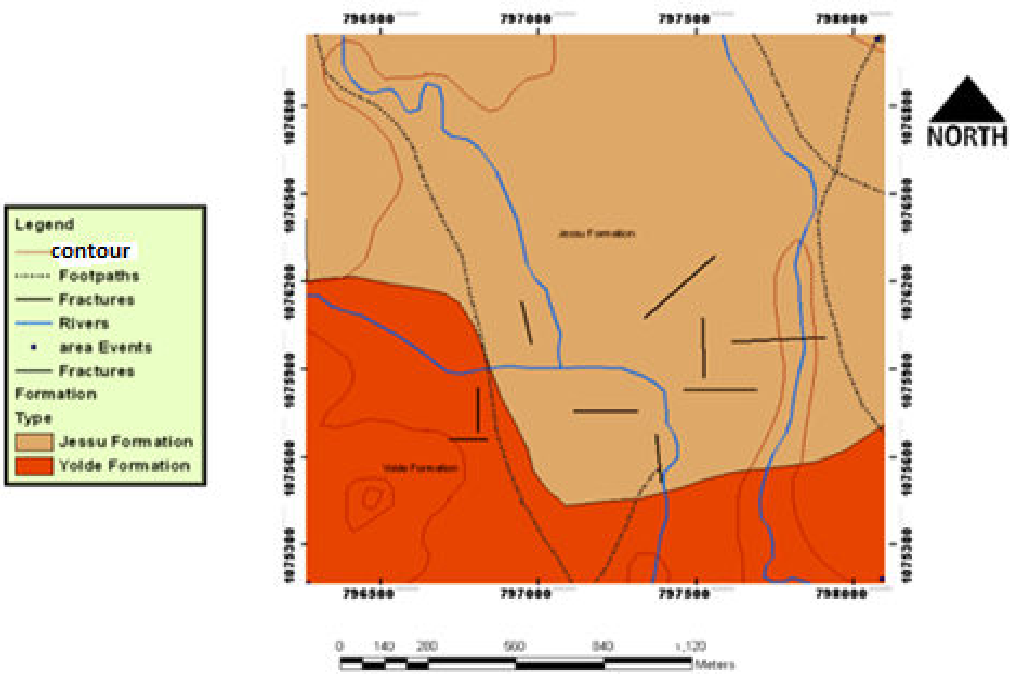

Figure 2: Geologic map of the Cham dam

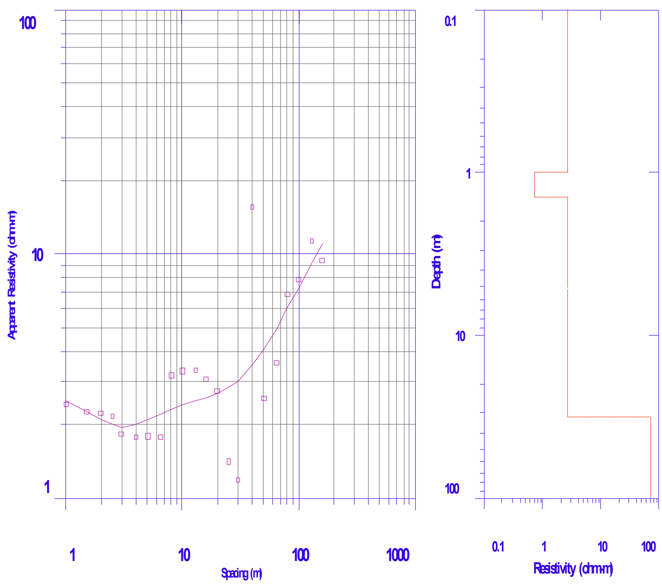

Figure 3: Resistivity Curve of VES 01

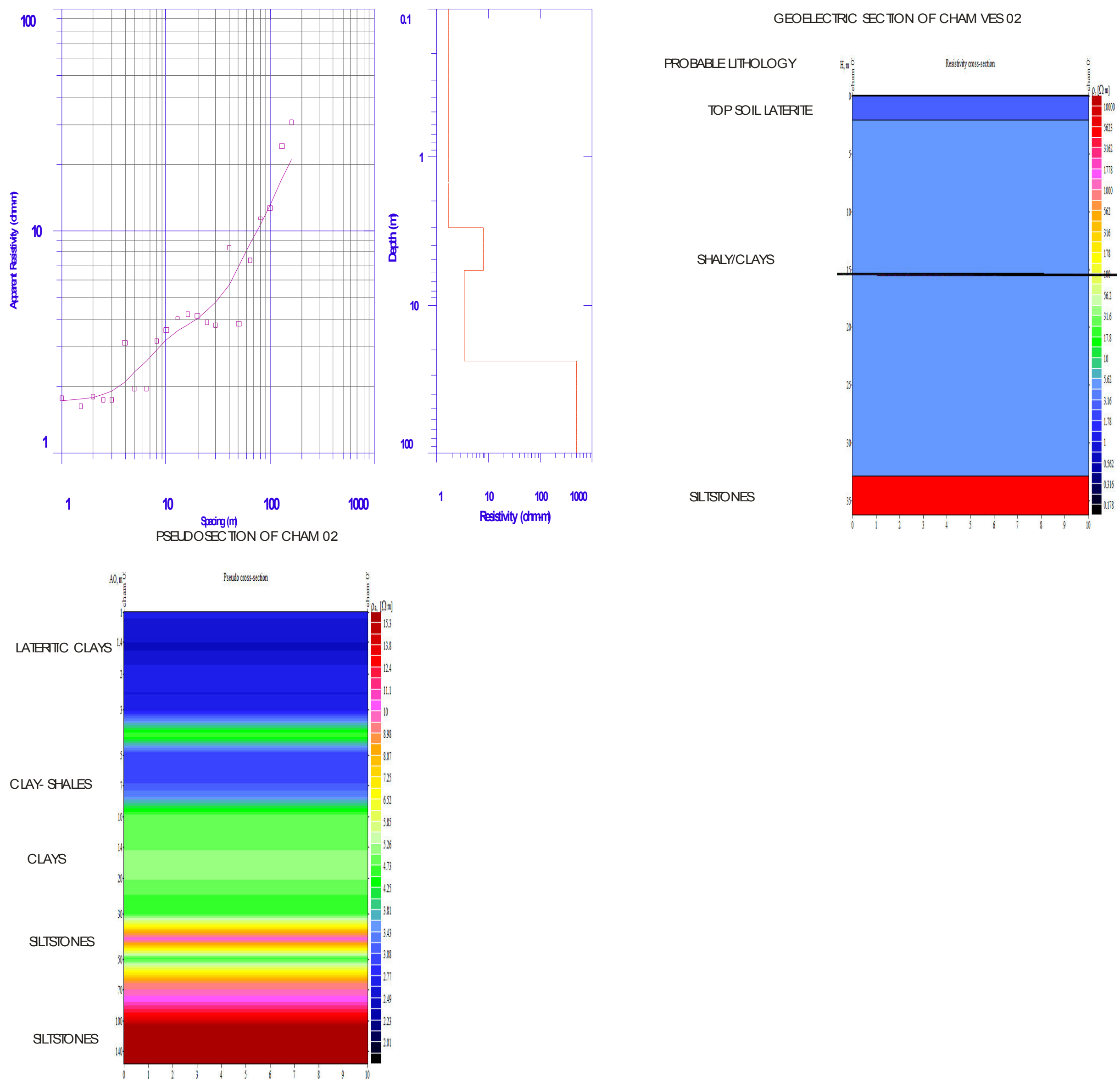

Figure 4 Resistivity Curve, Pseudo section and Geoelectrical Section for VES 02

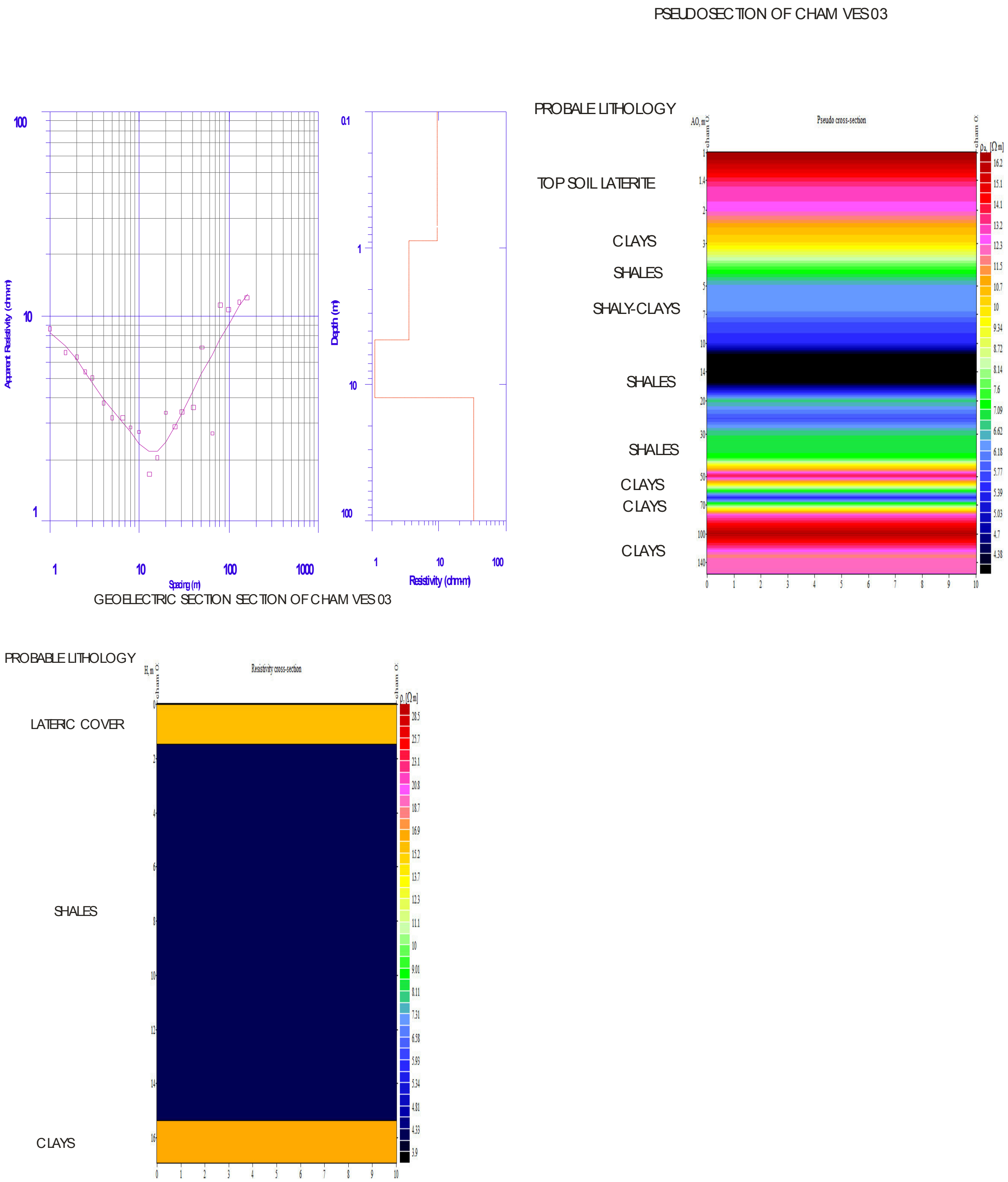

Figure 5 Resistivity Curve, Pseudosection and Geoelectrical Section for VES 03

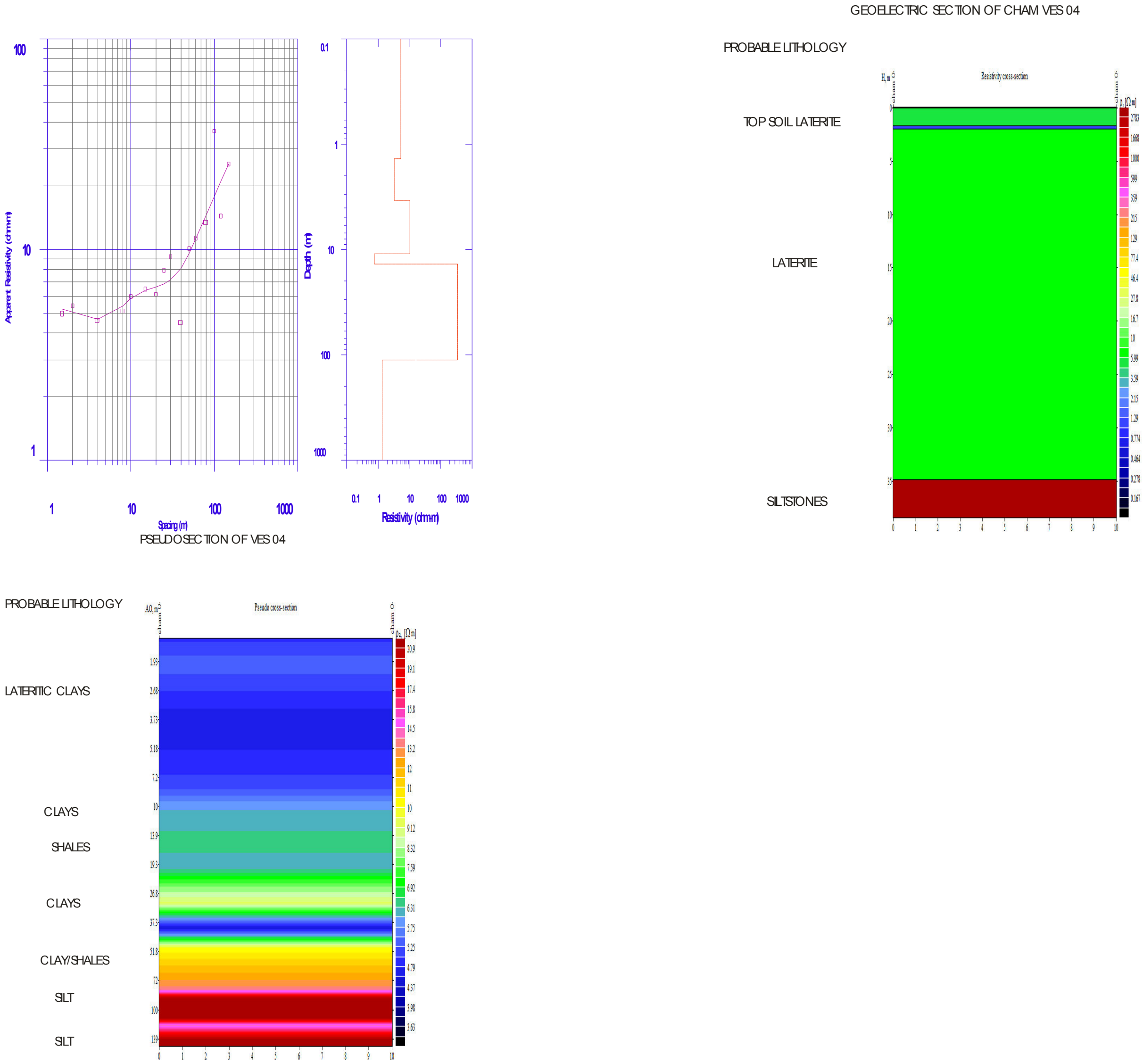

Figure 6 Resistivity Curve, Pseudo section and Geoelectrical section for VES 04

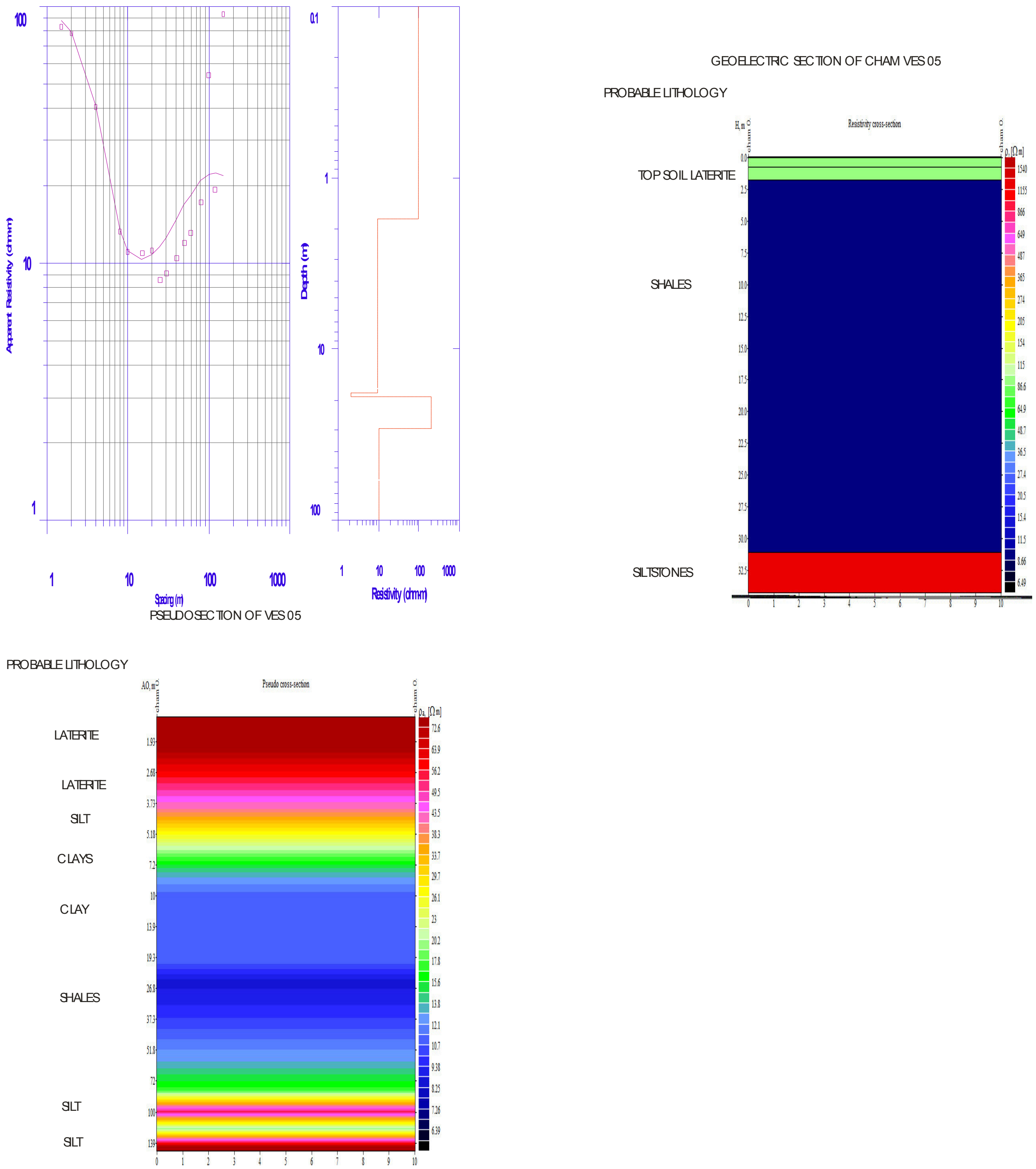

Figure 7 Resistivity Curve, Pseudo section and Geoelectrical Section for VES 05

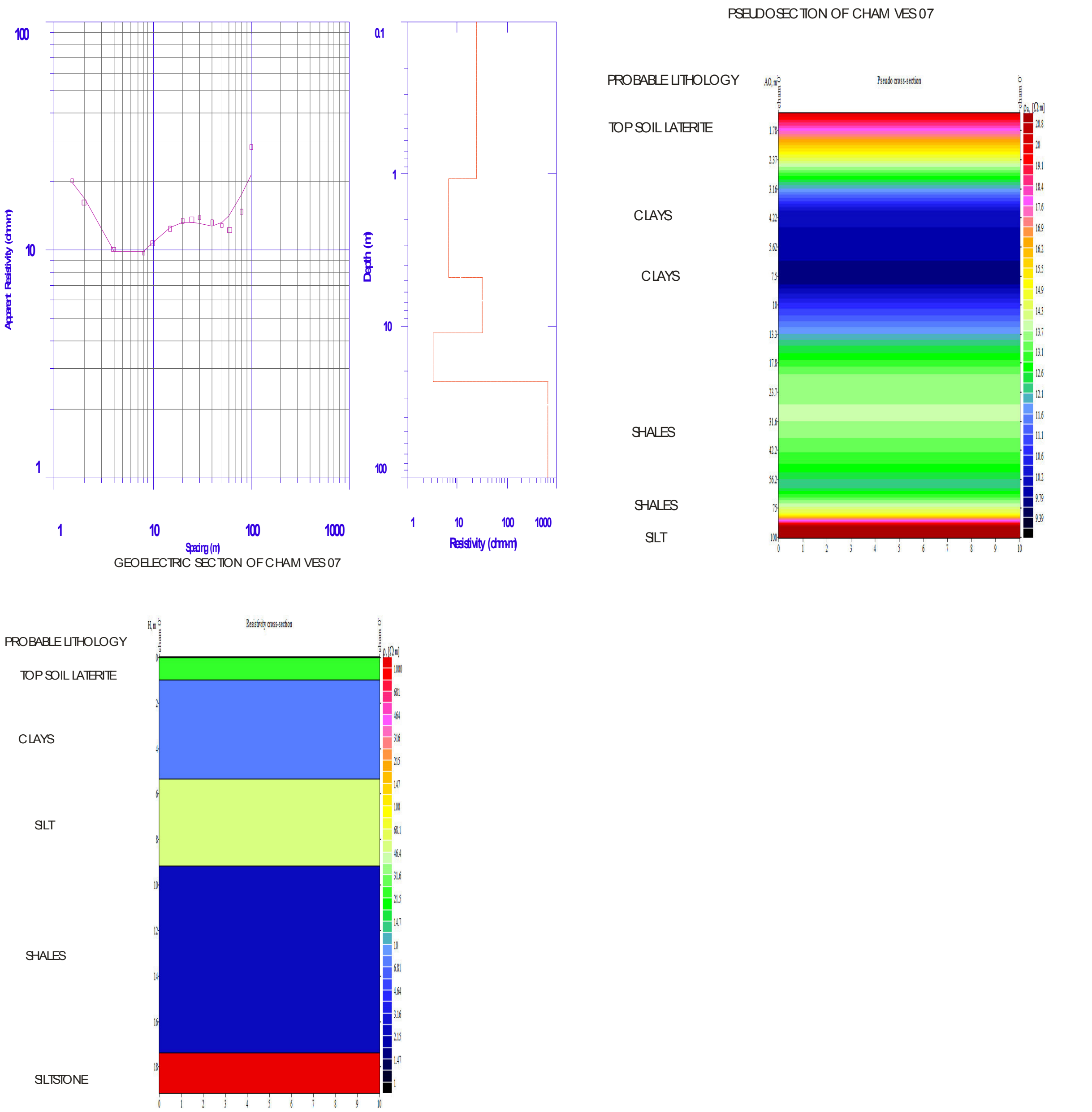

Figure 8 Resistivity Curve, Pseudo section and Geoelectrical Section for VES 06

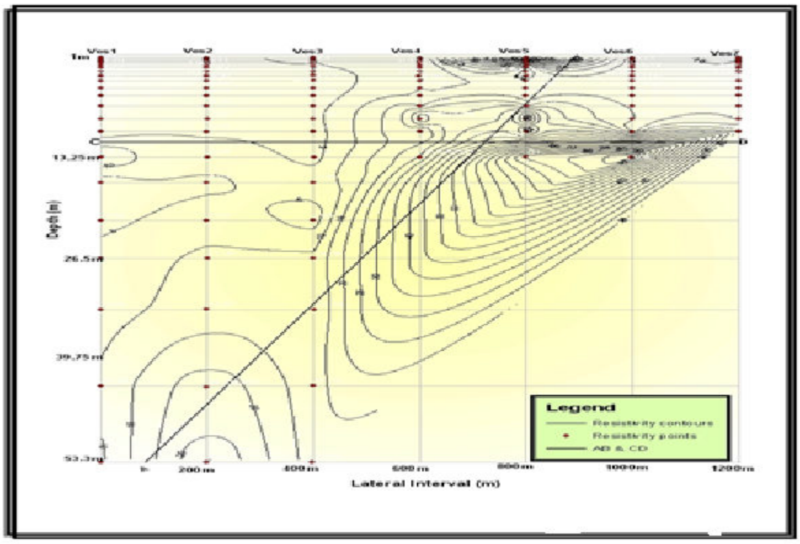

Figure 9: Resistivity contour map along Cham dam embankment

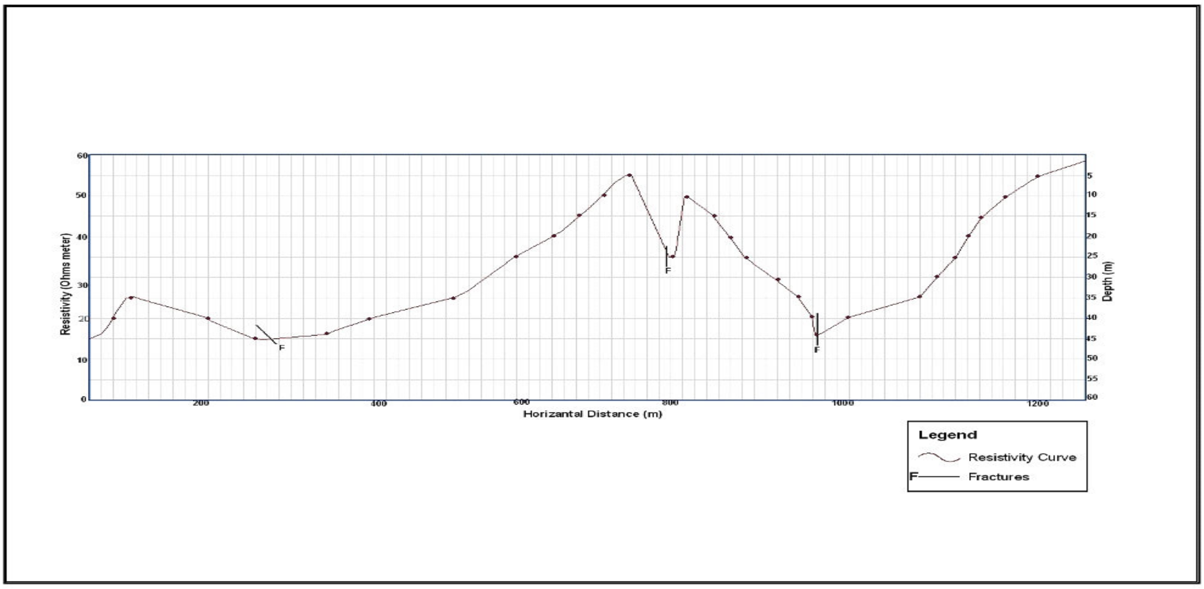

Figure10: Sub-surface resistivity profile along embankment

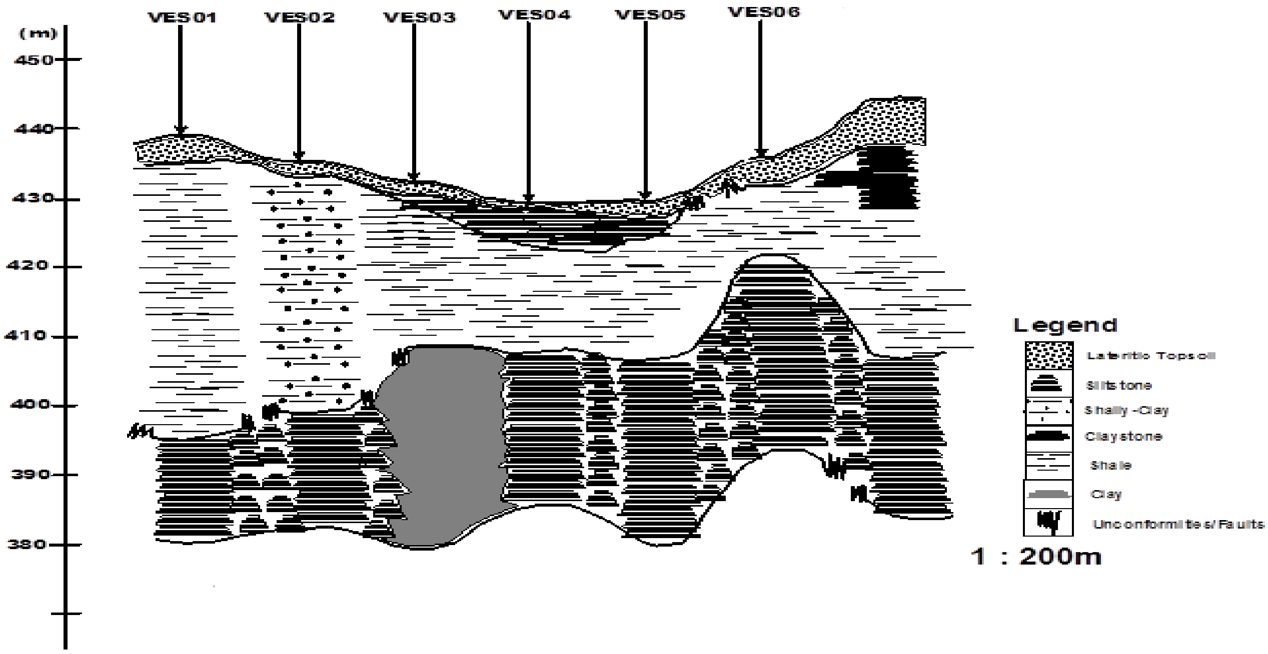

Figure11. Geoelectrical section of Cham dam axis (subsurface layers)